

# NREL NORTH AMERICAN SOLAR RADIATION ATLAS

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## ABSTRACT

This paper describes the online North American Solar Radiation Atlas, which displays solar collector performance at any location in the United States. The atlas is currently being developed at the National Renewable Energy Laboratory (NREL, Golden, CO). The new Atlas uses an interactive electronic map on the World Wide Web as an interface to multiple databases of solar collector performance and solar radiation data. The data delivered include estimated performance of various collector types such as tilted flat-plate surfaces, one- and two-axis tracking flat plate collectors, and concentrating collectors. The new World Wide Web user interface allows users to interact with maps of geographical features (terrain) and political features (state lines, county lines, cities, and roads) to select the location for which solar performance estimates are desired. Eventually, the Atlas will be a comprehensive electronic database of measured, modeled, and satellite-derived solar resource estimates, along with uncertainty statistics for the estimates at any location in the U.S.

The principal data source for the first prototype version of the Atlas is the Climatological Solar Radiation (CSR) model, developed by NREL to estimate climatological averages of daily-total solar radiation at a 40 km spatial resolution (1). The model uses, as input, monthly climatological mean values of cloud cover, precipitable water vapor, aerosol optical depth, surface albedo, and total column ozone. These input parameters are available from various sources such as the National Aeronautics and Space Administration (NASA) and the National Climatic Data Center (NCDC). The model allows us to calculate the output for the various collector types such as tilted flat-plate surfaces, one- and two-axis tracking flat plate collectors, and concentrating collectors. A previous paper (2) described the revised model and the validation of the model results for four different solar

collector orientations using ground-based measurements and models.

## 1. BACKGROUND

A key mission of the NREL Resource Assessment activity is to create techniques for estimating solar resources at any location, in a uniform way, and in a format usable by a wide range of end users. The principal product of this effort has been the U.S. National Solar Radiation Data Base (NSRDB), which contains hourly modeled and measured radiation data, as well as useful meteorological parameters for the 30-year period 1961-1990 (3). These time series data were created for 239 stations in the United States, Puerto Rico, and Guam. This includes 213 stations in the contiguous United States. An important practical application of the NSRDB is the "Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors" (4). For users in locations close to one of the 239 NSRDB sites, this provides a complete means of estimating the performance of many different solar collectors. In addition, a companion product, Typical Meteorological Years (TMY2), provides data that can be directly used to drive hourly simulations of PV systems, Concentrating Solar Power (CSP) facilities, hybrid systems, and building thermal performance, etc., giving accurate estimates of long-term performance at these locations (5).

Access to these estimates is available to any user through the Renewable Resource Data Center (<http://rredc.nrel.gov>). The available data summaries from the Solar Radiation Data Manual consist of spreadsheets with the monthly and annual estimates of collector performance for each collector type, maps for any month, and maps of the annual average. These maps are based on the 213 NSRDB data points (for the contiguous states) and thus do not closely follow

variations in climate and terrain. The interface to the data consists of a list of stations for the user to select from, or a map generator online form from which the user can choose the collector and month to be viewed.

Since 1996, NREL has also been producing maps of global horizontal, direct normal, and diffuse solar radiation using a technique called the “Solar Radiation Data Grid” (1). This procedure uses the NREL Climatological Solar Radiation (CSR) model, with input data derived from the best available climatological data for all locations. Our previous solar resource assessment products using the Data Grid techniques have been maps of countries or regions that show the solar resource available for each type of collector, usually with a contour interval of 1000 watt-hours/ m<sup>2</sup>/day. Within the last year, the model has been enhanced to produce all 14 collector orientations from the Solar Radiation Data Manual.

## 2. DATA GRID OUTPUTS.

NREL has developed the CSR model to estimate climatological averages of daily-total solar radiation at a 40 km spatial resolution. The CSR model is operational and has been usefully applied to the United States as well as several international areas. The outputs from the original version of CSR are monthly mean daily total values of global horizontal, direct normal, and diffuse radiation. Last year we revised the model to allow the calculation of the monthly mean output for the following 14 collector orientations, as described in the “Solar Radiation Data Manual.”

- 1) Flat-Plate Collector at Fixed Tilt=0
- 2) Flat-Plate Collector Facing South at Fixed Tilt=Latitude-15
- 3) Flat-Plate Collector Facing South at Fixed Tilt=Latitude
- 4) Flat-Plate Collector Facing South at Fixed Tilt=Latitude+15
- 5) Flat-Plate Collector Facing South at Fixed Tilt=90
- 6) 1-Axis Tracking Flat-Plate Collector with North-South Axis, Axis Tilt=0
- 7) 1-Axis Tracking Flat-Plate Collector with North-South Axis, Axis Tilt=Latitude-15
- 8) 1-Axis Tracking Flat-Plate Collector with North-South Axis, Axis Tilt=Latitude
- 9) 1-Axis Tracking Flat-Plate Collector with North-South Axis, Axis Tilt=Latitude+15
- 10) 2-Axis Tracking Flat-Plate Collector
- 11) 1-Axis Tracking Concentrating Collector with East-West Horizontal Axis

- 12) 1-Axis Tracking Concentrating Collector with North-South Horizontal Axis
- 13) 1-Axis Tracking Concentrating Collector with North-South Axis, Axis Tilt=Latitude
- 14) 2-Axis Tracking Concentrating Collector

The CSR model is a simplified version of the METSTAT model that was used to produce the NSRDB for the United States (3). Using the METSTAT algorithms, the CSR model calculates solar radiation energy for each 5-minute period from sunrise to sunset and then summarizes the 5-minute values to obtain a daily-total value. The 5-minute calculations are performed only for one day of each month—the day for which the daily-total extraterrestrial radiation (ETR) equals the monthly average daily-total ETR.

The current version of the CSR model uses only mean values for all daylight hours as inputs to the model. A major assumption inherent in the use of this technique for estimating climatological averages is that the CSR model, using only mean values as inputs and using only one day to represent 30 years, can produce averages representative of the 30 year means of the output parameters. This implies that there are not serious non-linearities in the model. The most important potential source of these non-linearities is the fact that, for all locations and all months, the model will be run on partly cloudy conditions, since the input is the average of all days. An average cloudiness of (for example) 40% is actually the result of a distribution of clear days, overcast days, and partly cloudy days. The CSR model will be most effective if the predicted radiation with 40% cloud cover is close to the average radiation with all cloud covers.

To assess the validity of this “Climatological Model Assumption,” we prepared a dataset with input values based on the 30-year mean of the NSRDB stations for each of the 213 verification stations in the contiguous United States (1). This dataset does not use any spatially derived input data other than the data used in the NSRDB. For each solar collector type from the Solar Radiation Data Manual, we compared the CSR model results using NSRDB inputs against the 30 year average tilted surface calculations in the Solar Radiation Data Manual. The residual differences should be due mostly to the Climatological Model Assumption.

The CSR model for nine collectors (2 through 10 above) use Perez algorithms to calculate the diffuse component incident on a tilted surface (6). The comparison of monthly average collector performance from the CSR model with the NSRDB shows a systematic 1% to 4% overestimate of the tilted flat-plate resource by the CSR model. These overestimates are highest in the winter, and disappear in the

summer. The likely cause of this is circumsolar radiation, which would tend to be higher under partly cloudy conditions than under either clear skies or overcast skies (R. Perez, private communication). For use in the National Solar Atlas, the Data Grid estimates for these collector types have been adjusted by removing the mean bias, averaged over the 213 stations in the contiguous United States, for each month.

### 3. GRAPHICAL USER INTERFACE

Users will be able to select their candidate location either by using a map or by entering the latitude and longitude. The information that is currently available at any location selected by the user includes:

- A single column of output showing monthly and annual radiation for one of the 14 collector orientations.
- Summarized estimates, annual and monthly, for all 14 collector orientations in a one-page spreadsheet text format similar to the one used in the “Solar Radiation Data Manual for Flat-plate and Concentrating Collectors.”
- Location of the nearest NSRDB/TMY2 station with links to data and maps for each station.

Features that will be available in later versions of the atlas will include:

- Regional maps of the resource available for each of the various collectors.
- Tutorial information to allow users to interpret these numbers, especially to identify potential sources of error (coastlines, mountains, and sources of dust or haze).
- Location of nearby sources of radiation data, with links to the sources of the data, to allow for a more comprehensive assessment of the solar resource characteristics, or to crosscheck the available data sources.
- A connection to the NREL PVWATTS photovoltaic performance calculator (see below).

The current prototype version of the Atlas interface is available on the World Wide Web at <http://maps.nrel.gov/newatlas.html>. The site is implemented using ArcView Internet Map Server (IMS) software, by Environmental Systems Research Institute, Inc. (ESRI). The user is presented with a map of the United States that is color-coded by terrain elevation (Fig 1). The stars represent the location of NSRDB stations. A toolbar allows the user to select “pan,” “zoom in,” “zoom out,” “data identity,” and “hot link” functions. The “zoom in” function works by

clicking and holding the mouse button in one corner of a desired box, dragging until the box covers the desired area, and releasing the mouse button. By zooming and panning interactively, the user homes in on the desired area.

When a sufficiently small-scale map is displayed (Fig 2), county lines appear, as do major cities and highways. Using the “data identity” tool, the user can query all of these features to identify their names. This should allow almost any user to determine the precise location of interest. In Fig 2, the area near Sequoia National Park in California has been chosen. This is an area of steep, complex terrain, with very high elevation in the Sierra Nevada mountains and very low elevations in the nearby Central Valley of California.

At the map scale shown in Fig 2, the outline of each data grid cell is visible. This indicates that solar resource data can now be accessed. The user can then choose which cell is most representative of his or her own location. Because the elevation of the user’s proposed site may not be well represented by the Data Grid cell containing the site, the user may wish to use a different grid cell, or to average solar radiation estimates from two or more cells. The “data identity” tool can then deliver one column of data for any of five different fixed flatplate solar collectors.

The “hot link” tool will deliver a data file for each location selected. For example, by selecting “hot link” and clicking the map in a cell near Sequoia National Park, we produce a data file for downloading and use in spreadsheet applications. The file can be saved directly from an ordinary web browser to the user’s hard drive. Table 1 shows the contents of this file after loading into a spreadsheet program. The data file contains a complete set of CSR model outputs including all 14 collector orientations.

Users most interested in standalone (non-grid connected) photovoltaics (PV) will use the CSR model outputs described above. For users interested in grid-connected PV, an NREL application known as PVWATTS (7) allows them to calculate the electrical output and the value for their own custom-designed PV system for any TMY2 (NSRDB) location. A future version of the PV Atlas will allow users to estimate this output for any location in the Data Grid, rather than just at the NSRDB sites. Other users will need to access surface radiation data from databases, which will also be accessible from the Atlas.

The National Solar Atlas will incorporate many new features over the next several years. This paper describes the first steps in the creation of this Atlas, and seeks feedback from the user community on its format and contents.

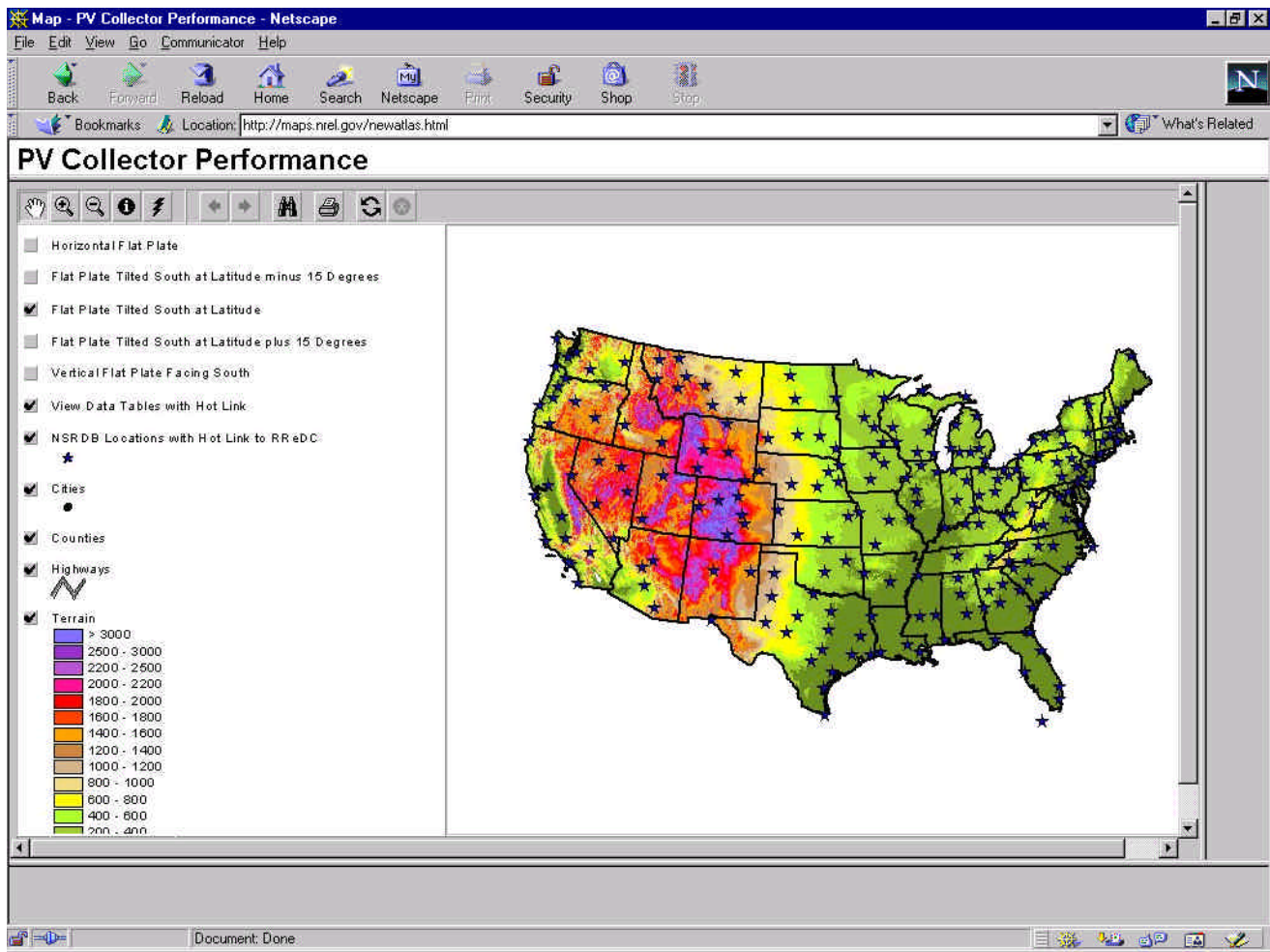


Fig 1: Initial screen for PV Atlas showing U.S. terrain map with NSRDB stations.



Cell No:	178355														
Lat:	36.45														
Long:	-118.55														
Elev(m):	2630														
Stn Type:	Data Grid														
SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage															
Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
0	Average	2.53	3.55	4.62	6.25	7.18	7.92	7.74	7.12	5.87	4.45	3.05	2.4	5.22	
Lat - 15	Average	3.63	4.71	5.51	6.83	7.28	7.7	7.64	7.5	6.81	5.81	4.38	3.59	5.95	
Lat	Average	3.98	4.96	5.54	6.48	6.64	6.93	7	7.12	6.65	6.05	4.76	3.99	5.84	
Lat + 15	Average	4.25	5.14	5.46	6.04	5.87	5.94	6.07	6.45	6.4	6.17	5.05	4.32	5.6	
90	Average	3.87	4.33	3.99	3.63	2.86	2.52	2.68	3.38	4.2	4.86	4.45	4.01	3.73	
SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage															
Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
0	Average	3.49	4.88	6.2	8.39	9.58	10.81	10.71	10.04	8.2	6.41	4.35	3.38	7.2	
Lat - 15	Average	4.24	5.65	6.78	8.77	9.67	10.73	10.71	10.33	8.81	7.28	5.22	4.18	7.7	
Lat	Average	4.63	5.99	6.95	8.72	9.4	10.31	10.34	10.16	8.91	7.64	5.67	4.63	7.78	
Lat + 15	Average	4.86	6.13	6.88	8.4	8.88	9.66	9.72	9.7	8.72	7.72	5.91	4.9	7.62	
SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty															
Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
2-Axis	Average	4.91	6.15	6.97	8.8	9.78	10.98	10.9	10.38	8.93	7.75	5.96	4.99	8.04	
DIRECT BEAM SOLAR RADIATION FOR CONCENTRATING COLLECTORS (kWh/m2/day), Percentage Uncertainty															
Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
1-X, E-W Hor	Average	2.87	3.49	3.6	4.63	5.28	6.37	6.28	6.01	5.19	4.83	3.81	3.12	4.62	
1-X, N-S Hor	Average	2.15	3.19	4.07	5.99	7.01	8.4	8.34	8.01	6.42	4.9	3.09	2.21	5.32	
1-X, N-S, Tilt=Lat	Average	3.1	4.14	4.7	6.24	6.78	7.86	7.91	8.06	7.05	6.05	4.28	3.29	5.79	
2-X	Average	3.31	4.25	4.71	6.33	7.17	8.55	8.5	8.31	7.07	6.12	4.5	3.57	6.03	

#### 4. REFERENCES

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